5 Do Early Warning Scores and Rapid Response Teams Improve Outcomes?

Gabriella Jäderling, Rinaldo Bellomo

The rapid expansion of medical knowledge and the advances in surgical techniques, drug treatments, and interventions make it possible to treat conditions that would have been untreatable only 50 years ago. Progress has also led to a change in demographics, with an unparalleled increase in the age of patients treated and, as a result, an increasing level of illness severity.[1]

These medical and social changes have coincided with alterations in hospital care. Such trends include health-care budget containments, cuts in the number of beds available, shortages of trained nurses, and working time directives. These new imperatives, which are associated with fewer and less experienced staff at hand to manage a larger workload of more complex patients, do not match the rising demand for admissions. Intensive care units (ICUs) have a proportionately limited number of beds to deal with such complex patients. Furthermore, the general wards, which lack sufficient monitoring, vigilance, and staffing resources, are being asked to provide care at levels usually reserved for ICUs. As a result of these system characteristics, patients whose condition deteriorates while on the general ward may not be identified and may not receive an appropriately high level of care in a timely manner.

Rapid Response Systems (RRSs) have been adopted in different forms worldwide to address the needs of such deteriorating patients in general wards. The RRS is an organized approach to improve patient safety by bridging care across hierarchies and specialties. RRSs facilitate the delivery of intensive care knowledge outside of the walls of the ICU, benefiting ward patients regardless of their location. The purpose is to detect and treat deviating physiology in time to prevent progression to irreversible conditions such as cardiac arrest or death.

Although intuitively appealing, some have questioned the evidence on which the implementation of an RRS rests. In this chapter, we present the concept of identifying and treating patients at risk using early warning scores (EWS) and RRSs as well as the emerging body of evidence in which these systems are evaluated.

DO EARLY WARNING SCORES HELP IDENTIFY PATIENTS AT RISK?

Adverse Events

Hospitals are dangerous places. In the early 1990s, several reports highlighted the occurrence of unexpected and potentially avoidable serious adverse events in hospitals.[2-4] These reports were not confined to a specific health-care system but were emerging from different parts of the world, thus forming the picture of a global problem.[5-11] Adverse events, defined as unintended injuries or complications caused by medical management rather than by the underlying disease and leading to death, disability, or prolonged hospital stays, were identified in between 2.9% and 16.6% of hospitalizations.[2,3,5,8-11] Up to 13.6% of such events were reported to lead to death and, importantly, 37% to 70% of these complications were deemed preventable. An in-hospital cardiac arrest is an example of a serious adverse event that is likely to have dire consequences. Despite dedicated efforts to improve resuscitation routines during cardiac arrest, mortality has remained unaltered at 85% to 90% over the past 30 years.[12-16] This lack of improvement could be explained by the fact that in-hospital cardiac arrests occurring in general wards are mostly related to noncardiac processes, with the arrest representing the common final pathway of various underlying disturbances.[17] As such, it is logical to hypothesize that outcome will improve with appropriate recognition and management of the precipitating disorder. Indeed, retrospective chart reviews suggest that this approach may well make it possible to avoid cardiac arrest altogether. In many, if not most, patients, signs of deterioration such as changes in pulse, blood pressure, respiratory rate, and mental status were present many hours before an actual arrest occurred.[17] Several studies have confirmed that this slow deterioration in vital signs may be present up to 48 hours before serious adverse events such as cardiac arrest, unanticipated ICU admission, or death.[18-23] These reports imply that the development of critical illness is not so much “sudden” but rather “suddenly recognized.”[24]

Early Warning Scores

The classic vital signs are temperature, pulse rate, blood pressure, and respiratory rate. Oxygen saturation, as measured by pulse oximetry, and level of consciousness may also constitute useful vital signs.[25-27] Development of a score/numerical value quantifying derangements of these easily measured physiologic markers, the so-called EWSs, thus has potential. The UK National Early Warning Score (NEWS) is shown for illustration (Fig. 5-1).

Assessment of a patient's vital signs is a routine component of in-hospital care. However, only rarely are detected abnormalities linked to specific responses. In the formulation of such a closed-loop system, it is essential to define assessment parameters that trigger a response.[28] Trigger systems can be categorized as single-parameter, multiple-parameter, aggregate weighted scoring, or combination systems.[24] The two most common are the single-parameter and the aggregate weighted scoring systems.

The first RRS was a single-parameter system.[29] The triggers were acute change in respiratory rate, pulse oximetry saturation, heart rate, systolic blood pressure, or conscious state or that the staff was simply worried about the patient because of specific conditions, physiologic abnormalities, and the subjective criterion "any time urgent help is needed or medical and nursing staff are worried." A deviation of any single parameter from its predefined cutoff level was enough to alert the team. These original RRS activating criteria are, with slight modifications, still in use in Australia, the United States, and parts of Europe. Advantages of the single-parameter system are ease of implementation and use and the provision of a binary response (call for help or not). The criteria consist of the observation of an acute change in respiratory rate, pulse oximetry saturation, heart rate, systolic blood pressure, conscious state, or that the staff are simply worried about the patient.

The subjective "worried" criterion is designed to empower the staff to activate a response whenever they are concerned about a patient. This approach relies on the intuition and experience of nurses and other providers and should not be underestimated because subtle symptoms or small changes observed by vigilant practitioners often turn out to be precursors to more objective physiologic changes.[30,31] Studies on several systems demonstrated that the worried criterion activated nearly half of RRS calls.[32-36]

In the aggregate weighted scoring systems, deviations of vital signs are assigned points. The sum of these points constitutes total scores that have been referred to as the EWS or Modified EWS.[37] Once a threshold score is reached, a response is triggered. Alternatively, a trend in the score can be followed and an increase over time can then be used to direct a graded escalation of care. However, this approach is relatively complex and time-consuming and depends on accurate calculation.[37,38] Variations of scoring systems with different triggers or additional parameters (e.g., urinary output) have been used. The Royal College of Physicians of the United Kingdom has recently proposed the application of a national standard, the NEWS,[39] to increase consistency and reproducibility.

EWS have been shown to predict the development of critical illness. Prospective prevalence studies of entire hospital populations have demonstrated that fulfilling criteria for abnormal vital signs is clearly associated with a worse outcome.[40-42] Most studies have focused on mortality, but derangements in vital signs also presage cardiac arrest and the need for ICU transfer.[43] However, the accuracy of scores can vary as a function of the chosen outcome parameter. In a comparison by Churpek et al.,[44] the areas under the curve for different EWSs ranged from 0.63 to 0.88, with prediction of mortality being the most accurate. A recent systematic review by Alam et al.[45] concluded that introduction of EWSs was associated with better clinical outcomes (improved survival and decreases of serious adverse events), although meta-analysis could not be performed because of the heterogeneity of the patient populations and lack of standardization of the scores used in the included studies.

There is no clear evidence to indicate which form of warning system is best or even what frequency of

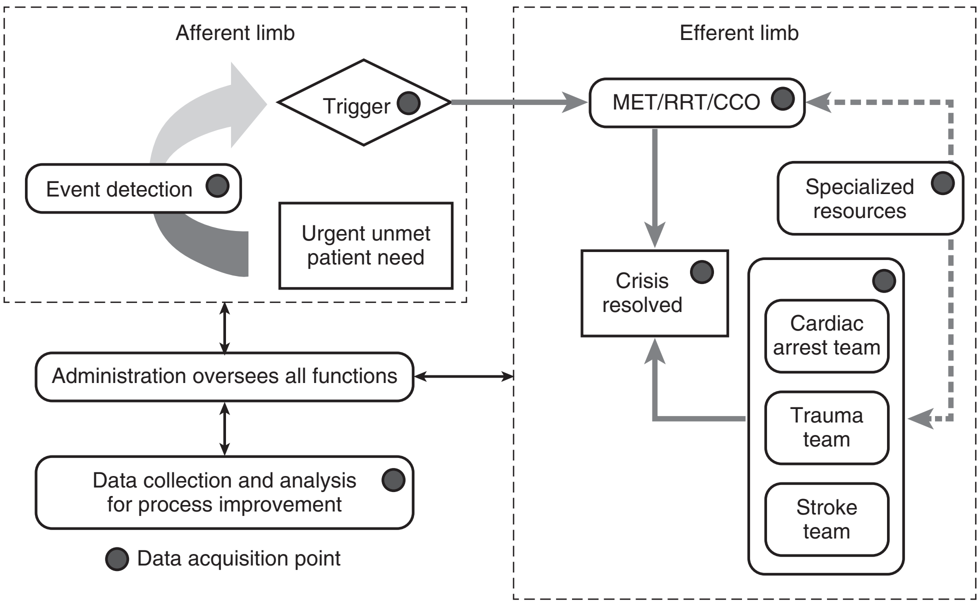

Figure 5-1. The composition of Rapid Response Systems. *CCO,* critical care outreach; *MET,* medical emergency team; *RRT,* rapid response team.

monitoring is ideal.[28] One study found a median duration of 6.5 hours for vital sign deteriorations before cardiac arrest,[46] whereas other studies found an even longer period.[18,21] Patients clearly respond better to earlier than delayed interventions.[47-50] In general, all systems provide reasonable specificity and negative predictive values but low sensitivity and positive predictive values.[51-53] Sensitivity can be improved by reducing the trigger threshold but not without compromising specificity, thus increasing workload. Including other parameters such as age,[54] comorbidities, or laboratory data[55,56] may improve predictive value.

Although many systems are in use, they differ primarily in details. Virtually all are based on the same concept: vital signs can provide clinicians with useful clues in evaluating a patient's condition or trajectory of illness. Implementing the use of any form of EWS conveys an important message: patients need to be checked. Placing the focus on monitoring and educating staff on when to react heightens awareness across the whole hospital; thus, it is likely to improve patient safety. In all probability, the value of an RRS lies not in the exact cutoffs or form of scores but rather in providing clear and objective tools to aid in assessing patients and in encouraging and empowering front-line providers to seek help when needed.

DO RAPID RESPONSE SYSTEMS IMPROVE OUTCOME?

General Principles of Rapid Response Systems

The usefulness and predictive value of EWSs must always be seen within the context of the response they can trigger. This response typically emanates from ICUs: dedicated teams that can be summoned to respond early to deteriorating patients, removing the usual boundaries of specialties and locations and centering care instead around the patients' needs.

Systems were simultaneously starting to take form in several parts of the world. An RRS is activated in Pittsburgh under the denotation "Condition C" (crisis) as opposed to "Condition A" (arrest), whereas in Australia the RRS is referred to as the "Medical Emergency Team" (MET). The first description in the literature appeared from an Australian center in 1995.[29] This report described the use of the team, its triggers, and the interventions provided. In the United Kingdom, a similar model was named the "Patient-at-Risk Team."[57] In 2005, the first international conference on METs was held in Pittsburgh, and faculty consensus findings were published. The report from this meeting defined a common nomenclature and composition and set the framework for future research.[58]

The term *Rapid Response System* refers to an entire network for responding to patients with a critical medical problem. The system comprises an afferent limb that detects the problem and triggers a response (Table 5-1). The responding team constitutes the efferent limb. This aspect may be of different designs, reflecting local culture and resources.

Teams that include physicians and nurses are traditionally called METs, whereas teams that are led by nurses are called RRSs. Critical Care Outreach teams are another model; they typically use ICU nurses as first responders and perform follow-up visits to patients discharged from the ICU. Outcome data on the superiority of one form to the other and the optimal composition of the team are lacking because there have been no studies directly comparing these different models.

Two additional components are needed to implement and maintain a successful RRS: an administrative framework and a feedback loop for quality evaluations (Fig. 5-1). These two are important because, in our opinion, only multilevel collaboration within the entire hospital organization can achieve a sustainable improvement of safety and quality in health care.

Outcome Measures

Measuring safety and monitoring success can be challenging in these complicated systems because the interventions are complex and are critically dependent on educational efforts and the context in which they are implemented.[59,60] Therefore process measures such as staff satisfaction, impact of education, or effects on end-of-life care are as important to investigate as traditional outcomes such as cardiac arrest rate, in-hospital mortality, and unanticipated ICU admission.

Table 5-1 **NEWS for United Kingdom National Health Scheme Hospitals**

Physiologic Parameters	3	2	1	0	1	2	3
Respiration rate	≤8		9–11	12–20		21–24	≥25
Oxygen saturation	≤91	92–93	94–95	≥96			
Any supplemental oxygen		Yes		No			
Temperature	≤35.0		35.1–38.0	38.1–39.0	≥39.1		
Systolic blood pressure	≤90	91–100	101–110	111–219			≥220
Heart rate	≤40		41–50	51–90	91–110	111–130	≥131
Level of consciousness				A			V, P, or U

From https://www.rcplondon.ac.uk/.../national-early-warning-score-standardising-assessment-acute-illness-severity-nhs.pdf
NEWS, National Early Warning Score; *a,* alert; *P,* pain; *U,* unresponsive; *V,* voice.

RRSs have been widely adopted and endorsed by patient safety organizations, but there has been conflicting evidence regarding their value. Several "before-and-after" studies have shown a significant decrease in cardiac arrest rate, with reductions ranging from 20% to 65%.[32,61-64] Other reports have not been able to confirm an effect.[65] Evidence supporting reductions in cardiac arrests is more robust than in overall mortality[32,61,65-69] (see Table 5-2 for a summary). Most studies have been performed in single centers, but there are two reports in which hospitals are concurrently compared with and without an RRS. Bristow et al.[66] compared one hospital with an RRS to two hospitals with only conventional cardiac arrest teams and found that the RRS hospital had fewer unanticipated admissions to the ICU and high dependency unit but not a significant difference in cardiac arrest rates or mortality. Chen et al.[70] recently compared a hospital with a mature RRS to three hospitals without RRSs and found that the cardiac arrest rate was 50% lower and overall hospital mortality was 6% lower in the institution with mature RRS. In addition, introducing an RRS was associated with a 22% reduction in cardiac arrest rate and an 11% reduction in overall mortality.

Performing clinical trials of RRSs is problematic because randomization on an individual patient level (to either receive increased vigilance of deterioration with a targeted response or not) is ethically and practically unsound. However, two randomized studies have been published. Priestley et al.[69] performed a ward-based randomization of an outreach service and showed a significant reduction in hospital mortality. These studies also suggest that hospital length of stay was increased. The largest randomized trial is MERIT, a cluster randomization of 23 hospitals in Australia.[71] No outcome benefit was detected, although both trial arms improved relative to baseline. It has been argued that this study was underpowered,[72] that the teams were inadequately implemented,[73] and that there was contamination between the sites because control hospitals actually adopted RRS principles and used their cardiac arrest teams in RRS-like activities. However, an in-depth look into MERIT and its findings found that timely intervention by any team resulted in a significant reduction in cardiac arrests and unexpected hospital deaths.[48]

There have been variable reports of effects on unanticipated ICU admission. The MERIT trial did not demonstrate a difference. However, other data are equivocal. Several nonrandomized trials found a decrease,[66,74,75] two others found no effect,[76,77] and one found an increase.[61] ICU admission represents a potentially problematic endpoint because it is affected by local policies, bed numbers and occupancy, and resource availability. Such findings should be placed in context because an increase in low-acuity ICU admissions may decrease mortality rates, but it may represent a poor use of resources. Estimates of length of stay are equally difficult to interpret. Survivors may have a long length of stay, whereas the extremely ill who die shortly after admission will not. Furthermore, this measure may again be influenced by local policies in addition to medical decisions.

Two recent high-quality systematic reviews addressed RRSs.[78,79] In 2010, Chan et al.[78] identified 18 published studies, examining nearly 1.3 million admissions. Of the studies that reported team composition, 13 of 16 were led by physicians. The utilization of the team, or dose, was (in median) 15.1 of 1000 admissions (range, 2.5-40.3) in adult studies and 7.5 (range, 2.8-12.8) in pediatric studies. The analysis demonstrated a pooled risk reduction of 33.8% for adult cardiac arrest rates (relative risk [RR] 0.66, 95% confidence interval [CI] 0.54-0.80) but no significant effect on hospital mortality (RR 0.79, 95% CI 0.84-1.09). The pooled risk reduction in the five pediatric studies was 37.7% for cardiac arrest rates (RR 0.62, 95% CI 0.46–0.84) and 21.4% for hospital mortality (RR 0.79, 95% CI 0.63-0.98). The study concluded that RRSs were associated with reduced rates of in-hospital cardiac arrests but consistent evidence of improved overall hospital survival was lacking.

Winters et al.[79] conducted a systematic review in 2013 to include more recent evidence and found 26 additional studies on the effectiveness of RRSs (3 of which were conducted on children) and 17 additional studies addressing RRS implementation. The implementation processes varied widely and were driven by local needs and resources. Most studies described education as an integral part of implementation, although not all involved formal training. It has been posited that the use of an RRS may give rise to unintended consequences, some of which may be harmful. These concerns include deterioration in the resuscitative skills of ward staff, but this particular issue has been refuted in several qualitative studies. Rather, data indicate that nurse satisfaction is generally increased and that the system is highly appreciated in part because it provides a sense of security and improves patient care as well as the work environment.[80-83] Thus, this updated review supported the conclusions of Chan et al., but it also found that more recent studies reported favorable results, perhaps reflecting maturation of the systems and improvements in implementations. One study also adjusted for possible trends over time and found that reductions in cardiac arrest rates and mortality were unaffected.[36] In summary, it was concluded that the evidence supporting the use of RRSs to improve outcomes of hospitalized patients was moderately strong.

Ethical Issues

Over time, the use of RRSs has led to ethical concerns. Specifically, the deployment of an RRS often required the team to discuss and arrive at a quick conclusion regarding escalation of care. Although not an initial goal, several studies have reported the involvement of an RRS team in end-of-life care decisions.[84-88] An international multicenter study showed that one third of RRS calls were for patients in whom there were specific limitations in medical therapy. Furthermore, activation of the RRS frequently occurred after hours, and in 10% of cases the RRS was directly involved in designating patients "not for resuscitation."[86] It was also noted that the existence of a limitation in care did not exclude patients from RRS calls.[88] These findings suggest that wards need support not only in advanced care planning but also in providing comfort or appropriate treatment for patients with limitations of treatment orders. Such a patient may in fact improve as

Table 5-2 Summary of Studies Investigating the Effect of RRSs on Clinical Outcomes

Author, Year, Country	Study Design	Team Composition and Trigger System	Outcomes Studied	Results
Bristow,[66] 2000, Australia	Concurrent multicenter cohort comparison	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality, unplanned ICU admission	No effect on cardiac arrests or mortality, decreased ICU admissions
Buist,[61] 2002, Australia	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	50% reduction of cardiac arrests, no effect on hospital mortality
Bellomo,[32] 2003, Australia	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	65% reduction of cardiac arrests, 26% reduction of hospital mortality
Bellomo[68] 2004, Australia	Observational before-after	Physician-led, single-parameter score	Hospital mortality in postoperative patients after major surgery	36% reduction of hospital mortality
Kenward,[65] 2004, England	Observational before-after	Not reported, aggregate weighted score	Cardiac arrest rate, hospital mortality	No effect
Priestley,[69] 2004, England	Randomized on ward basis	Nurse-led outreach service, aggregate weighted score	Hospital mortality, hospital length of stay	48% reduction of hospital mortality
DeVita,[63] 2004, United States	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate	17% reduction of cardiac arrests
Hillman,[71] 2005, Australia	Cluster-randomized controlled trial	Physician-led, single-parameter score	Composite of cardiac arrests, unplanned ICU admission, unexpected death	No effect, both groups reduced cardiac arrests and unexpected deaths as compared with baseline
Jones,[64] 2005, Australia	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate	53% reduction of cardiac arrests
Jones,[89] 2007, Australia	Observational before-after	Physician-led, single-parameter score	Long-term mortality in postoperative patients	23% reduction in mortality at 1500 days after major surgery
Dacey,[74] 2007, United States	Observational before-after	Physician assistant-led, single-parameter score	Cardiac arrest rate, hospital mortality, unplanned ICU admission, ICU length of stay	61% reduction of cardiac arrests, no effect on hospital mortality, 16% decrease of unplanned ICU admissions
Jolley,[90] 2007, United States	Observational before-after	Nurse-led, single-parameter score	Cardiac arrest rate, hospital mortality	No effect
Offner,[91] 2007, United States	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate	50% reduction of cardiac arrests
Baxter,[92] 2008, Canada	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, ICU admissions and readmissions, hospital mortality	38% reduction of cardiac arrests, decrease in ICU admissions and readmissions, no effect on hospital mortality
Chan,[67] 2008, United States	Observational before-after	Nurse-led, single-parameter score	Cardiac arrest rate, hospital mortality	41% reduction of non-ICU cardiac arrests, no effect on hospital mortality
Campello,[93] 2009, Portugal	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	27% reduction of cardiac arrests, no effect on hospital mortality
Konrad,[62] 2010, Sweden	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	26% reduction of cardiac arrests, 10% reduction of overall hospital mortality
Lighthall,[94] 2010, United States	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	57% reduction of cardiac arrests, trend toward lower mortality
Santamaria,[95] 2010, Australia	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality, unexpected ICU admission	Significant reductions of cardiac arrests and hospital mortality, no effect on ICU admissions

Continued

Table 5-2 Summary of Studies Investigating the Effect of RRSs on Clinical Outcomes—cont'd

Author, Year, Country	Study Design	Team Composition and Trigger System	Outcomes Studied	Results
Laurens,[96] 2011, Australia	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality, unexpected ICU admission	45% reduction of cardiac arrests, 24% reduction of hospital mortality, 21% reduction of unexpected ICU admissions
Beitler,[36] 2011, United States	Observational before-after	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	51% reduction of cardiac arrests, 11% reduction in hospital-wide mortality, 35% reduction in out-of-ICU mortality
Sarani,[97] 2011, United States	Observational before-after/retrospective review	Physician-led, single-parameter score	Cardiac arrest rate, hospital mortality	40% reduction of cardiac arrests in medical patients, 32% in surgical, 25% reduction in hospital mortality for medical patients, no effect on surgical
Shah,[98] 2011, United States	Observational before-after/retrospective review	Nurse-led, single-parameter score	Cardiac arrest rate, hospital mortality, unplanned ICU admissions	No effect
Tobin,[99] 2012, Australia	Retrospective review of administrative data	Physician-led, single-parameter score	Hospital mortality	10% decrease in adjusted hospital-wide mortality 4 years after the introduction of MET
Chen,[70] 2014, Australia	Concurrent comparison of a hospital with a mature RRS and three hospitals without RRS	Not reported	Cardiac arrest rates, hospital mortality	50% lower cardiac arrest rate in RRS hospital and 6% lower mortality; after introducing an RRS, the other hospitals decreased their cardiac arrest rates 22% with an 11% drop in mortality

ICU, intensive care unit.

a result of RRS actions (e.g., by receiving antibiotics or fluids). However, the limitations for more advanced care, such as cardiopulmonary resuscitation or invasive ventilation, will not alter outcome in a favorable way and must be honored.

Therefore the manner by which RRSs decrease cardiac arrests may result from earlier detection and treatment of deteriorations; thus, they may truly prevent cardiac arrest. However, value may also arise as a result of increased discussions of the indications for treatment and of the limitations imposed at end of life, thus reducing the use of cardiopulmonary resuscitation and other resuscitative measures in terminally ill patients who have other needs.

The number of patients seen by an RRS is not proportional to an actual decrease in mortality. It may be that the RRS affects more than just the number of calls delivered. The intense educational efforts that are a part of RRS implementation increase general knowledge and awareness among the staff of failing vital signs. This change in itself may result in ancillary positive effects, providing ward staff with the tools to correctly recognize and manage early signs of deterioration,[80] thus obviating the need to call the RRS team. This potential benefit is a crucial part of the system that is difficult to quantify but nonetheless has a pivotal influence on how hospitalized patients are cared for and hence on their outcome.

AUTHORS' RECOMMENDATIONS

- All hospital patients should have an individual monitoring plan. This may be revised according to the development of a patient's clinical status during hospitalization.
- EWSs can be used to predict the development of critical illness and perform reasonably well in the identification of patients at risk. However, there is no clear evidence to indicate which form of EWS is best.
- Components of a successful RRS include adequate trigger criteria for activation (afferent limb); a response team of competent composition (efferent limb); and an administrative and quality improvement component for educating staff, collecting data, and maintaining the system.
- There is moderate strength of evidence that RRSs decrease cardiac arrest rates and hospital mortality. EWSs and RRSs promote a patient-focused safety culture and increase understanding of the importance of measuring and understanding vital signs.

REFERENCES

1. Hillman K, Parr M, Flabouris A, et al. Redefining in-hospital resuscitation: the concept of the medical emergency team. *Resuscitation*. 2001;48(2):105–110.
2. Brennan TA, Leape LL, Laird NM, et al. Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. *N Engl J Med*. 1991;324(6):370–376.

3. Leape LL, Brennan TA, Laird N, et al. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. *N Engl J Med*. 1991;324(6):377–384.
4. Kohn L, Corrigan J, Donaldson M. *To Err is Human: Building a Safer Health System*. Washington, DC: Institute of Medicine, National Academies Press; 1999.
5. Wilson RM, Runciman WB, Gibberd RW, et al. The quality in Australian health care study. *Med J Aust*. 1995;163(9):458–471.
6. Thomas EJ, Studdert DM, Burstin HR, et al. Incidence and types of adverse events and negligent care in Utah and Colorado. *Med Care*. 2000;38(3):261–271.
7. Vincent C, Neale G, Woloshynowych M. Adverse events in British hospitals: preliminary retrospective record review. *BMJ*. 2001;322(7285):517–519.
8. Davis P, Lay-Yee R, Briant R, et al. Adverse events in New Zealand public hospitals I: occurrence and impact. *N Z Med J*. 2002;115(1167):U271.
9. Baker GR, Norton PG, Flintoft V, et al. The Canadian Adverse Events Study: the incidence of adverse events among hospital patients in Canada. *CMAJ*. 2004;170(11):1678–1686.
10. Soop M, Fryksmark U, Koster M, et al. The incidence of adverse events in Swedish hospitals: a retrospective medical record review study. *Int J Qual Health Care*. 2009;21(4):285–291.
11. Zegers M, de Bruijne MC, Wagner C, et al. Adverse events and potentially preventable deaths in Dutch hospitals: results of a retrospective patient record review study. *Qual Saf Health Care*. 2009;18(4):297–302.
12. Peatfield RC, Sillett RW, Taylor D, et al. Survival after cardiac arrest in hospital. *Lancet*. 1977;1(8024):1223–1225.
13. Bedell SE, Delbanco TL, Cook EF, et al. Survival after cardiopulmonary resuscitation in the hospital. *N Engl J Med*. 1983;309(10):569–576.
14. Schneider 2nd AP, Nelson DJ, Brown DD. In-hospital cardiopulmonary resuscitation: a 30-year review. *J Am Board Fam Pract*. 1993;6(2):91–101.
15. Peberdy MA, Kaye W, Ornato JP, et al. Cardiopulmonary resuscitation of adults in the hospital: a report of 14720 cardiac arrests from the National Registry of Cardiopulmonary Resuscitation. *Resuscitation*. 2003;58(3):297–308.
16. Sandroni C, Nolan J, Cavallaro F, et al. In-hospital cardiac arrest: incidence, prognosis and possible measures to improve survival. *Intensive Care Med*. 2007;33(2):237–245.
17. Schein RM, Hazday N, Pena M, et al. Clinical antecedents to in-hospital cardiopulmonary arrest. *Chest*. 1990;98(6):1388–1392.
18. Hillman KM, Bristow PJ, Chey T, et al. Antecedents to hospital deaths. *Intern Med J*. 2001;31(6):343–348.
19. Franklin C, Mathew J. Developing strategies to prevent inhospital cardiac arrest - analyzing responses of physicians and nurses in the hours before the event. *Critical Care Medicine*. 1994;22(2):244–247.
20. Hillman KM, Bristow PJ, Chey T, et al. Duration of life-threatening antecedents prior to intensive care admission. *Intensive Care Med*. 2002;28(11):1629–1634.
21. Kause J, Smith G, Prytherch D, et al. A comparison of antecedents to cardiac arrests, deaths and emergency intensive care admissions in Australia and New Zealand, and the United Kingdom–the ACADEMIA study. *Resuscitation*. 2004;62(3):275–282.
22. Buist M, Bernard S, Nguyen TV, et al. Association between clinically abnormal observations and subsequent in-hospital mortality: a prospective study. *Resuscitation*. 2004;62(2):137–141.
23. Smith AF, Wood J. Can some in-hospital cardio-respiratory arrests be prevented? A prospective survey. *Resuscitation*. 1998;37(3):133–137.
24. DeVita M, Hillman K, Bellomo R. Textbook of rapid response systems – concept and implementation. In: *Book Textbook of Rapid Response Systems - Concept and Implementation*. Springer; 2011. City.
25. Mower WR, Myers G, Nicklin EL, et al. Pulse oximetry as a fifth vital sign in emergency geriatric assessment. *Acad Emerg Med*. 1998;5(9):858–865.
26. Neff TA. Routine oximetry. A fifth vital sign? *Chest*. 1988;94(2):227.
27. Flaherty JH, Rudolph J, Shay K, et al. Delirium is a serious and under-recognized problem: why assessment of mental status should be the sixth vital sign. *J Am Med Dir Assoc*. 2007;8(5):273–275.
28. DeVita MA, Smith GB, Adam SK, et al. "Identifying the hospitalised patient in crisis"–a consensus conference on the afferent limb of rapid response systems. *Resuscitation*. 2010;81(4):375–382.
29. Lee A, Bishop G, Hillman KM, et al. The Medical Emergency Team. *Anaesth Intensive Care*. 1995;23(2):183–186.
30. Cioffi J. Recognition of patients who require emergency assistance: a descriptive study. *Heart Lung*. 2000;29(4):262–268.
31. Cioffi J, Conwayt R, Everist L, et al. 'Patients of concern' to nurses in acute care settings: a descriptive study. *Aust Crit Care*. 2009;22(4):178–186.
32. Bellomo R, Goldsmith D, Uchino S, et al. A prospective before-and-after trial of a medical emergency team. *Med J Aust*. 2003;179(6): 283–287.
33. Santiano N, Young L, Hillman K, et al. Analysis of medical emergency team calls comparing subjective to "objective" call criteria. *Resuscitation*. 2009;80(1):44–49.
34. Jaderling G, Calzavacca P, Bell M, et al. The deteriorating ward patient: a Swedish-Australian comparison. *Intensive Care Med*. 2011;37(6):1000–1005.
35. Hodgetts TJ, Kenward G, Vlachonikolis IG, et al. The identification of risk factors for cardiac arrest and formulation of activation criteria to alert a medical emergency team. *Resuscitation*. 2002;54(2):125–131.
36. Beitler JR, Link N, Bails DB, et al. Reduction in hospital-wide mortality after implementation of a rapidresponse team: a long-term cohort study. *Crit Care*. 2011;15(6):R269.
37. Subbe CP, Gao H, Harrison DA. Reproducibility of physiological track-and-trigger warning systems for identifying at-risk patients on the ward. *Intensive Care Med*. 2007;33(4):619–624.
38. Prytherch DR, Smith GB, Schmidt P, et al. Calculating early warning scores–a classroom comparison of pen and paper and hand-held computer methods. *Resuscitation*. 2006;70(2):173–178.
39. National Early Warning Score (NEWS): standardising the assessment of acute illness severity in the NHS. Report of a working party. In: *Book National Early Warning Score (NEWS): Standardising the assessment of acute illness severity in the NHS*. Royal College of Physicians; 2012. Report of a working party.
40. Bell MB, Konrad D, Granath F, et al. Prevalence and sensitivity of MET-criteria in a Scandinavian University Hospital. *Resuscitation*. 2006;70(1):66–73.
41. Fuhrmann L, Lippert A, Perner A, et al. Incidence, staff awareness and mortality of patients at risk on general wards. *Resuscitation*. 2008;77(3):325–330.
42. Bucknall TK, Jones D, Bellomo R, et al. Responding to medical emergencies: system characteristics under examination (RESCUE). A prospective multi-site point prevalence study. *Resuscitation*. 2012;84:179–183.
43. Churpek MM, Yuen TC, Edelson DP. Predicting clinical deterioration in the hospital: the impact of outcome selection. *Resuscitation*. 2013;84(5):564–568.
44. Churpek MM, Yuen TC, Edelson DP. Risk stratification of hospitalized patients on the wards. *Chest*. 2013;143(6):1758–1765.
45. Alam N, Hobbelink EL, van Tienhoven AJ, et al. The impact of the use of the Early Warning Score (EWS) on patient outcomes: a systematic review. *Resuscitation*. 2014;85(5):587–594.
46. Buist MD, Jarmolowski E, Burton PR, et al. Recognising clinical instability in hospital patients before cardiac arrest or unplanned admission to intensive care. A pilot study in a tertiary-care hospital. *Med J Aust*. 1999;171(1):22–25.
47. Kumar A, Roberts D, Wood KE, et al. Duration of hypotension before initiation of effective antimicrobial therapy is the critical determinant of survival in human septic shock. *Crit Care Med*. 2006;34(6):1589–1596.
48. Chen J, Bellomo R, Flabouris A, et al. The relationship between early emergency team calls and serious adverse events. *Crit Care Med*. 2009;37(1):148–153.
49. Cardoso LT, Grion CM, Matsuo T, et al. Impact of delayed admission to intensive care units on mortality of critically ill patients: a cohort study. *Crit Care*. 2011;15(1):R28.
50. Boniatti MM, Azzolini N, Viana MV, et al. Delayed medical emergency team calls and associated outcomes. *Crit Care Med*. 2014;42(1):26–30.
51. Gao H, McDonnell A, Harrison DA, et al. Systematic review and evaluation of physiological track and trigger warning systems for identifying at-risk patients on the ward. *Intensive Care Med*. 2007;33(4):667–679.
52. Smith GB, Prytherch DR, Schmidt PL, et al. Review and performance evaluation of aggregate weighted 'track and trigger' systems. *Resuscitation*. 2008;77(2):170–179.

53. Smith GB, Prytherch DR, Schmidt PE, et al. A review, and performance evaluation, of single-parameter "track and trigger" systems. *Resuscitation*. 2008;79(1):11–21.
54. Smith GB, Prytherch DR, Schmidt PE, et al. Should age be included as a component of track and trigger systems used to identify sick adult patients? *Resuscitation*. 2008;78(2):109–115.
55. Prytherch DR, Sirl JS, Schmidt P, et al. The use of routine laboratory data to predict in-hospital death in medical admissions. *Resuscitation*. 2005;66(2):203–207.
56. Loekito E, Bailey J, Bellomo R, et al. Common laboratory tests predict imminent medical emergency team calls, intensive care unit admission or death in emergency department patients. *Emerg Med Australas*. 2013;25(2):132–139.
57. Goldhill DR, Worthington L, Mulcahy A, et al. The patient-at-risk team: identifying and managing seriously ill ward patients. *Anaesthesia*. 1999;54(9):853–860.
58. Devita MA, Bellomo R, Hillman K, et al. Findings of the first consensus conference on medical emergency teams. *Crit Care Med*. 2006;34(9):2463–2478.
59. Delaney A, Angus DC, Bellomo R, et al. Bench-to-bedside review: the evaluation of complex interventions in critical care. *Crit Care*. 2008;12(2):210.
60. Hillman K, Chen J, May E. Complex intensive care unit interventions. *Crit Care Med*. 2009;37(1 Suppl):S102–S106.
61. Buist MD, Moore GE, Bernard SA, et al. Effects of a medical emergency team on reduction of incidence of and mortality from unexpected cardiac arrests in hospital: preliminary study. *BMJ*. 2002;324(7334):387–390.
62. Konrad D, Jäderling G, Bell M, et al. Reducing in-hospital cardiac arrests and hospital mortality by introducing a medical emergency team. *Intensive Care Med*. 2010;36(1):100–106.
63. DeVita MA, Braithwaite RS, Mahidhara R, et al. Use of medical emergency team responses to reduce hospital cardiopulmonary arrests. *Qual Saf Health Care*. 2004;13(4):251–254.
64. Jones D, Bellomo R, Bates S, et al. Long term effect of a medical emergency team on cardiac arrests in a teaching hospital. *Crit Care*. 2005;9(6):R808–R815.
65. Kenward G, Castle N, Hodgetts T, et al. Evaluation of a medical emergency team one year after implementation. *Resuscitation*. 2004;61(3):257–263.
66. Bristow PJ, Hillman KM, Chey T, et al. Rates of in-hospital arrests, deaths and intensive care admissions: the effect of a medical emergency team. *Med J Aust*. 2000;173(5):236–240.
67. Chan PS, Khalid A, Longmore LS, et al. Hospital-wide code rates and mortality before and after implementation of a rapid response team. *JAMA*. 2008;300(21):2506–2513.
68. Bellomo R, Goldsmith D, Uchino S, et al. Prospective controlled trial of effect of medical emergency team on postoperative morbidity and mortality rates. *Crit Care Med*. 2004;32(4):916–921.
69. Priestley G, Watson W, Rashidian A, et al. Introducing Critical Care Outreach: a ward-randomised trial of phased introduction in a general hospital. *Intensive Care Med*. 2004;30(7):1398–1404.
70. Chen J, Ou L, Hillman K, et al. The impact of implementing a rapid response system: a comparison of cardiopulmonary arrests and mortality among four teaching hospitals in Australia. *Resuscitation*. 2014;85(9):1275–1281.
71. Hillman K, Chen J, Cretikos M, et al. Introduction of the medical emergency team (MET) system: a cluster-randomised controlled trial. *Lancet*. 2005;365(9477):2091–2097.
72. Chen J, Flabouris A, Bellomo R, et al. Baseline hospital performance and the impact of medical emergency teams: modelling vs. conventional subgroup analysis. *Trials*. 2009;10:117.
73. Cretikos MA, Chen J, Hillman KM, et al. The effectiveness of implementation of the medical emergency team (MET) system and factors associated with use during the MERIT study. *Crit Care Resusc*. 2007;9(2):206–212.
74. Dacey MJ, Mirza ER, Wilcox V, et al. The effect of a rapid response team on major clinical outcome measures in a community hospital. *Crit Care Med*. 2007;35(9):2076–2082.
75. Ball C, Kirkby M, Williams S. Effect of the critical care outreach team on patient survival to discharge from hospital and readmission to critical care: non-randomised population based study. *British Medical Journal*. 2003;327(7422):1014–1016A.
76. Leary T, Ridley S. Impact of an outreach team on re-admissions to a critical care unit. *Anaesthesia*. 2003;58(4):328–332.
77. Garcea G, Thomasset S, McClelland L, et al. Impact of a critical care outreach team on critical care readmissions and mortality. *Acta Anaesthesiol Scand*. 2004;48(9):1096–1100.
78. Chan PS, Jain R, Nallmothu BK, et al. Rapid response teams: a systematic review and meta-analysis. *Arch Intern Med*. 2010;170(1):18–26.
79. Winters BD, Weaver SJ, Pfoh ER, et al. Rapid-response systems as a patient safety strategy: a systematic review. *Ann Intern Med*. 2013;158(5 Pt 2):417–425.
80. Jones D, Baldwin I, McIntyre T, et al. Nurses' attitudes to a medical emergency team service in a teaching hospital. *Qual Saf Health Care*. 2006;15(6):427–432.
81. Galhotra S, Scholle CC, Dew MA, et al. Medical emergency teams: a strategy for improving patient care and nursing work environments. *J Adv Nurs*. 2006;55(2):180–187.
82. Salamonson Y, van Heere B, Everett B, et al. Voices from the floor: Nurses' perceptions of the medical emergency team. *Intensive Crit Care Nurs*. 2006;22(3):138–143.
83. Shapiro SE, Donaldson NE, Scott MB. Rapid response teams seen through the eyes of the nurse. *Am J Nurs*. 2010;110(6):28–34. quiz 35–26.
84. Chen J, Flabouris A, Bellomo R, et al. The Medical Emergency Team System and not-for-resuscitation orders: results from the MERIT study. *Resuscitation*. 2008;79(3):391–397.
85. Jones DA, McIntyre T, Baldwin I, et al. The medical emergency team and end-of-life care: a pilot study. *Crit Care Resusc*. 2007;9(2):151–156.
86. Jones DA, Bagshaw SM, Barrett J, et al. The role of the medical emergency team in end-of-life care: A multicenter, prospective, observational study. *Crit Care Med*. 2012;40(1):98–103.
87. Parr MJ, Hadfield JH, Flabouris A, et al. The Medical Emergency Team: 12 month analysis of reasons for activation, immediate outcome and not-for-resuscitation orders. *Resuscitation*. 2001;50(1):39–44.
88. Jaderling G, Bell M, Martling CR, et al. Limitations of medical treatment among patients attended by the rapid response team. *Acta Anaesthesiol Scand*. 2013;57(10):1268–1274.
89. Jones D, Egi M, Bellomo R, et al. Effect of the medical emergency team on long-term mortality following major surgery. *Crit Care*. 2007;11(1):R12.
90. Jolley J, Bendyk H, Holaday B, et al. Rapid response teams: do they make a difference?. *Dimens Crit Care Nurs*. 2007;26(6):253–260. quiz 261–252.
91. Offner PJ, Heit J, Roberts R. Implementation of a rapid response team decreases cardiac arrest outside of the intensive care unit. *J Trauma*. 2007;62(5):1223–1227. discussion 1227–1228.
92. Baxter AD, Cardinal P, Hooper J, et al. Medical emergency teams at The Ottawa Hospital: the first two years. *Can J Anaesth*. 2008;55(4):223–231.
93. Campello G, Granja C, Carvalho F, et al. Immediate and long-term impact of medical emergency teams on cardiac arrest prevalence and mortality: a plea for periodic basic life-support training programs. *Crit Care Med*. 2009;37(12):3054–3061.
94. Lighthall GK, Parast LM, Rapoport L, et al. Introduction of a rapid response system at a United States veterans affairs hospital reduced cardiac arrests. *Anesth Analg*. 2010;111(3):679–686.
95. Santamaria J, Tobin A, Holmes J. Changing cardiac arrest and hospital mortality rates through a medical emergency team takes time and constant review. *Crit Care Med*. 2010;38(2):445–450.
96. Laurens N, Dwyer T. The impact of medical emergency teams on ICU admission rates, cardiopulmonary arrests and mortality in a regional hospital. *Resuscitation*. 2011;82(6):707–712.
97. Sarani B, Palilonis E, Sonnad S, et al. Clinical emergencies and outcomes in patients admitted to a surgical versus medical service. *Resuscitation*. 2011;82(4):415–418.
98. Shah SK, Cardenas Jr VJ, Kuo YF, et al. Rapid response team in an academic institution: does it make a difference? *Chest*. 2011;139(6):1361–1367.
99. Tobin AE, Santamaria JD. Medical emergency teams are associated with reduced mortality across a major metropolitan health network after two years service: a retrospective study using government administrative data. *Crit Care*. 2012;16(5):R210.